HUNT (T. S.)

Dr. O. W. Holmes.
with the respects of
T. Sterry Hunt.

PREFACE

TO A NEW EDITION OF

CHEMICAL AND GEOLOGICAL ESSAYS.

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PREFACE

TO THE SECOND EDITION.

In revising this volume for a new edition, it was felt that the introduction of any changes in the Essays themselves would be at variance with the plan of the work, which was to preserve in their original form certain papers, the value of which is in part historical. The author has therefore confined himself to the correction of typographical errors in the text; but takes this occasion to present some extended comments and critical notes upon certain geological questions discussed in the Essays, with regard to which decided progress has been made since the publication of the first edition.

On pages 46–48 is a suggestion, made many years since, regarding the question of the temperature of the earth's surface in former geological periods, which, from its bearings, both direct and indirect, on some recent geological theories, calls for farther notice. From the great amount of carbon and hydrocarbons of organic origin found in the rocky strata of the earth, it has long been inferred that the atmosphere of earlier times must have contained a large quantity of carbonic dioxyd, which yielded up its carbon for the nutrition of the ancient floras. From this the late Major Edwin B. Hunt concluded that the atmosphere in former periods being much denser than at present, the temperature at the earth's surface,

due to solar radiation, would be greater than now. It was subsequently pointed out by the present writer that, as already shown by Tyndall, the relations of carbonic dioxyd to radiant heat are such that a quantity of this gas too small to affect considerably the weight of the atmospheric column would, by preventing the loss of heat, suffice to produce a tropical temperature over the earth at the sea-level.

The quantity of carbon which has been removed from the air by vegetation in past ages is, however, very considerable. In a communication by the writer to the American Association for the Advancement of Science, at Buffalo, in 1866, it was stated that the whole amount of free oxygen in the present atmosphere is no more than sufficient to form carbonic dioxyd with the carbon of a layer of coal covering the globe one meter in thickness, and that the aggregate of carbonaceous matter in the earth's crust would probably much exceed this. Such a layer of coal, of specific gravity 1.25, would have a weight equal to 3,160,000 gross tons to the square mile, while Mr. J. L. Mott, in a communication to the British Association for the Advancement of Science, in 1877, estimates the total amount of carbonaceous substances in the earth at not less than 3,000,000 tons of carbon to the square mile, and probably many times greater. This minimum amount of pure carbon is equal to 600 times the present amount of carbonic dioxyd in the atmosphere, or to nearly one fourth its entire volume; and, inasmuch as the fixation of carbon by vegetation liberates a corresponding volume of oxygen, would represent, according to him, a greater amount of this gas than the present atmosphere contains. In addition to this, it must be considered that the composition of the various hydrocarbonaceous minerals shows a deoxydation not only of carbonic dioxyd but of water. The amount of liberated oxygen derived from water

equals, for the various coals and asphalts, from one eighth to one fourth, and for the petroleums one half of that set free in the deoxydation of the carbon which these hydrocarbonaceous bodies contain. To this must be added also the oxygen set free in the generation of metallic sulphids by the deoxydation of sulphates, which is effected through the agency of organic matters, and indirectly liberates oxygen. Against this we must however set the unknown but very considerable amount of oxygen absorbed in the peroxydation of ferrous oxyd liberated in the decay of the silicates of crystalline rocks; which may, perhaps, serve to explain the disappearance from the air of the whole of this excess of oxygen.

The terrestrial vegetation and the air-breathing fauna, which we find from paleozoic ages, are, it is unnecessary to remark, incompatible with an atmosphere holding one fourth its volume of carbonic dioxyd, and the difficulty of the problem is greatly increased when we consider that this amount, corresponding to the carbon fixed in the earth's crust in deoxydized forms, is insignificant when compared with that which has been absorbed during the decomposition of silicated rocks, and is now fixed in the form of limestones. The magnitude of this process is seen when we consider that all the argillaceous rocks and clays of the stratified formations have come from the decay of the feldspars and other silicates of the earlier eozoic terranes through the intervention of carbonic dioxyd, and that the resulting alkaline and earthy carbonates are now represented by the limestones so abundant in the earth's crust. It was shown, in the author's communication already quoted, that a layer of pure limestone covering the earth's surface to a depth of about twenty-eight feet (8.61 meters) corresponds to an amount of carbonic dioxyd which,

if set free, would double the weight of the present atmosphere, and the existence of great limestone and dolomite formations, many hundred feet in thickness, at different geological horizons over wide areas, will, it is believed, justify the conclusion that the earth's crust contains, fixed in the form of carbonates, an amount of carbonic dioxyd which, if liberated in a gaseous form, would be equal in weight to at least two hundred atmospheres like the present one. A portion of this carbonic acid was doubtless separated at an early period in the history of our globe, since the limestones of the eozoic rocks are of considerable thickness, and those of more recent times are in part derived from the solution and redeposition of the older limestones.

The only known sources of carbonic dioxyd, apart from combustion and respiration, are certain terrestrial exhalations of the gas, probably due to chemical reactions liberating small portions which had long before been fixed in the form of carbonates. We are thus forced to one of two conclusions: either the wholly improbable one that the atmosphere since the appearance of organic life on the earth has been one of nearly pure carbonic dioxyd, and of such immense extent that the pressure at the surface would have sufficed, at ordinary temperatures, for its liquefaction; or else, the atmosphere being so constituted as to permit vital processes, that carbonic dioxyd, as fast as removed by chemical action at the earth's surface, was supplied from some extra-terrestrial source. We may, in accordance with this last hypothesis, admit that the atmosphere is not terrestrial but cosmical, and that the air, together with the water surrounding our globe (whether in a liquid or a vaporous state), belongs to a common elastic medium which, extending throughout the interstellary spaces, is condensed around attracting bodies in amounts pro-

portional to their mass and temperature, while in the regions most distant from these centres of attraction, this universal atmosphere would exist in the state of greatest tenuity. Such being the case, a change in the atmosphere of any globe, whether by the absorption or disengagement of any gas or vapor, would, by the laws of diffusion and of static equilibrium, be felt everywhere throughout the universe; and the fixation of carbonic dioxyd at the surface of our planet would not only bring in a supply of this gas from the worlds beyond, but, by reducing the total amount of it in the universal atmosphere, would diminish the atmospheric pressure at the surface of our own and of other worlds.

This hypothesis is not altogether new. Sir William R. Grove, in 1842, put forth the notion that the medium of heat and light may be "an universally diffused matter," and subsequently, in 1843, in his celebrated Essay on the Correlation of Physical Forces, in the chapter on Light, concludes, with regard to the atmosphere of the sun and the planets, that there is no reason why these atmospheres "should not be, with reference to each other, in a state of equilibrium. Ether, which term we may apply to the highly attenuated matter existing in the interplanetary spaces, being an expansion of some or all of these atmospheres, or of the more volatile portions of them, would thus furnish matter for the transmission of the modes of motion which we call light, heat, etc., and possibly minute portions of these atmospheres may, by gradual accretions and subtractions, pass from planet to planet, forming a link of material communication between the distant monads of the universe." Subsequently, in his address as President of the British Association for the Advancement of Science, in 1866, Grove farther suggested that this diffused matter might be a source of solar heat, inasmuch as the sun

may "condense gaseous matter as it travels in space, and so heat may be produced."

In 1870, Mr. W. Mattieu Williams, who does not seem to have been acquainted with these views, published his ingenious work entitled "The Fuel of the Sun," which is little more than a development of the suggestions of Grove. The source of solar heat, according to him, is the condensation by the sun of the attenuated matter or ether everywhere encountered by that body in its motion through interstellary space. The heat which, from sun and planets, is radiated into space, is thus first absorbed by the ether, and then again concentrated and redistributed by the sun.

Dr. P. Martin Duncan, in his address as President of the Geological Society of London, in May, 1877, without noticing the priority of Grove, has adopted from Williams the notion of a cosmical atmosphere, but supposes that the sun, in virtue of its greater mass, is slowly attracting to itself the greater part of the earth's atmospheric envelope. From this view he proceeds to deduce important geological considerations, conceiving that, from the greater height of the terrestrial atmosphere, which, according to his hypothesis, must have prevailed in former ages, there would have resulted a higher temperature at the earth's surface, more aqueous vapor, a more equable climate, and a prolonged twilight at the poles. From a more abundant precipitation greater sub-aerial denudation would follow, and although local glaciation of high mountains might occur, the existence of masses of ice at the earth's surface, or for some thousands of feet above it, would be impossible.

If, however, the principles which have been already advanced are correct, it is not to solar attraction that we are to attribute a progressive diminution in the height of the

atmospheric column, but to the various processes going on in the worlds, whereby the atmospheric elements are condensed in the form of liquid water or fixed as hydrates, oxyds, or carbonates. The operation of such processes in our own and other planets in past ages must have produced a considerable refrigeration of climate by reducing the weight of the atmosphere, and a still more marked result of the same kind by diminishing the proportion of carbonic dioxyd contained therein, as has already been pointed out.

Two questions here present themselves in connection with the problem of the earth's climate from the appearance of terrestrial vegetation until now: 1. Has the mean annual temperature of the globe during this period ever been less? 2. Has it ever been greater than at present? It is shown by paleontological evidence that a very warm or subtropical climate prevailed over the arctic regions during the carboniferous, triassic, jurassic, and lower cretaceous times, following which we find in the upper cretaceous a commencement of refrigeration, although until the close of the miocene a vegetation like that now characterizing the middle temperate zone flourished in far northern latitudes. After this came the cold of the pliocene age, which, with some variations, has continued until now. That the arctic cold has at times extended over certain continental areas farther southward than at present, is undoubted; but this — the mean annual temperature of the globe being the same as now — might result from changed geographical conditions. A new distribution of land and water might bring back again the reindeer to France, or give to Labrador the climate of Ireland. More than this, geographical changes are conceivable which, permitting the influx of warm currents into the polar seas, would create even there an insular climate of exceeding mildness. The

studies of Nordenskiöld have, however, shown that a warm climate prevailed there in the carboniferous age over a great area of land, which supported a colossal vegetation not unlike that then flourishing in the intertropical climates of the earth. It is inconceivable that, with an atmosphere constituted like that of the present day, any geographical conditions could maintain during the long winter nights such a climate in insular regions, and still less over a continental area within the polar circle. We are therefore forced to the conclusion that geographical changes, though a true cause of local variations of climate, and adequate to explain the greater refrigeration of certain areas since the commencement of the pliocene, are not sufficient to account for the warmer climates of previous ages; and we conclude that the cause of these is to be found in the former greater volume and different chemical constitution of the atmosphere, as already set forth.

This view is opposed to the hypothesis maintained by many geologists of an alternation of warm and glacial climates at the surface of the earth, repeated from the earlier times. Dawson and Heer, however, from the study of the fossil floras found in arctic regions from the Devonian to the miocene, conclude that paleontology affords no evidence of such a condition of things, and the observations of McCoy, Hector, and Hutton in the southern hemisphere lead them to similar conclusions. The nursery of these successive northern floras appears to have been in the arctic regions, and their spread southward would, according to Dawson, be due to continental elevations, bringing about, at irregular periods, a cooler climate in the northern temperate zone. It may even be conceived, as well remarked by J. F. Campbell, that such elevations might bring large areas of the earth's surface into the region of perpetual frost, thus giving rise to local glacial

phenomena, while a warm climate prevailed everywhere at the sea-level. Nordenskiöld declares that he sought in vain for evidences of ice-action in the various sedimentary deposits of Spitzbergen.

In regard to a suggested explanation of former climatic conditions, the author may be permitted to quote the following language used by him in 1876. "Recent speculations have revived the old notion of a possible change of the earth's axis of rotation, as a way of explaining this change of arctic climate; but such a phenomenon is astronomically improbable, and is also opposed by the fact that the direction of the oceanic currents, which are guided by the earth's rotation, appears, from the distribution of marine sediments, to have been the same since very early periods." * Dawson has since urged the same argument, and reinforced it by recalling the fact that the southward migrations of successive floras, not less than the lines of distribution of mechanical sediments in past ages, show that from early paleozoic time the general courses of the oceanic currents, and consequently the position of the earth's axis, have not changed.

In connection with the hypothesis of a universal atmosphere may be mentioned a speculation which was put forth by the author in an address delivered by him in July, 1874, at the grave of Priestley, in Northumberland, Pennsylvania, entitled "A Century's Progress in Theoretical Chemistry," and published in the American Chemist for that year (vol. V., pp. 46-51). An extract therefrom, under the title of "Celestial Chemistry," appeared in the Popular Science Monthly (vol. VII., p. 420). In that address, after referring to the results of the spectroscopic study of the stars, and to the increase in the chemical complexity of their spectra which appears in passing from the white to the yellow and red stars, it was said: —

* Harper's Annual Record of Science for 1876, p. cii.

"If, in accordance with the nebular hypothesis, we look upon these different types of stars as representing successive stages in the process of condensation from nebula to planet, we may also see in them a gradual evolution of the more complex from the simpler forms of matter by a process of celestial chemistry. Such was the view put forward by F. W. Clarke, in January, 1873,* and some months later by Lockyer, who has reiterated and enforced these suggestions, and moreover connected them with the speculations of Dumas on the composite nature of the elements. . . . I ventured in 1867, while speculating on the phenomena of dissociation, to remark that, although from the experiments of the laboratory we can only conjecture the complex nature of the so called elementary substances, we may expect that their 'further dissociation in stellar or nebulous masses may give us evidence of matter still more elemental.'"†

The green line in the spectrum of the solar chromosphere, which has been supposed to show therein the existence of a hitherto unknown gaseous element, was then noticed, and it was added: "Is it not possible that we have here that more elemental form of matter which, though not seen in the nebulæ, is liberated by the intense heat of the solar sphere, and may possibly correspond to the primary matter conjectured by Dumas, having an equivalent weight one fourth that of hydrogen? Mention should also be made of the unknown element conjectured by Huggins to exist in some nebulæ. This conception of a first matter, or *Urstoff*, has also been maintained by Hinrichs, who has put forward an argument in its favor from a consideration of the wave-lengths in the lines of the spectra of various elements."

* Evolution and the Spectroscope: Popular Science Monthly, volume II., page 320.

† See page 37 of the present volume.

"It is curious in this connection to note that Lavoisier suggested that hydrogen, nitrogen, and oxygen, with heat and light, might be regarded as simpler forms of matter from which all others were derived. The nebulæ, which we conceive as condensing into suns and planets, show us only two of the three elements of our terrestrial envelope, which is made up of air and aqueous vapor. If now we admit, as I am disposed to do, with [Sir William R. Grove and] W. Mattieu Williams that our atmosphere and ocean are not simply terrestrial but cosmical, and are a portion of the medium which, in an attenuated form, fills the interstellary spaces, these same nebulæ and their resulting worlds may be evolved by a process of chemical condensation from this universal atmosphere, to which they would sustain a relation somewhat analogous to that of clouds and rain to the aqueous vapor around us. This, though it may be regarded as a legitimate and plausible speculation, is at present nothing more, and we may never advance beyond conjecture as to the relations of the various forms of so-called elemental matter, and to the processes which govern the evolution of the starry spheres."

The Taconic rocks have of late been the object of much study on the part of the author, leading him to conclude that what has been said of them in Essay XIII. Part 1, and in Essay XV. Part 3, is true only of that portion which Emmons at first included in the upper part of his Taconic system under the general name of the Taconic slates, but in 1855 separated from the underlying portions, and described as the Upper Taconic series. This is no other than the Quebec group of Logan, which is the northward prolongation of the Taconic slates from eastern New York. The rocks in the Hudson valley, to which Mather, in his Fourth Annual Report on the Geology of New York (in 1840), gave the name of the

Hudson River slates or the Hudson slate group, included these Upper Taconic rocks, together with portions of strata holding the fauna of the upper members of the Champlain division. The strata of this region, and of its extension north and south, including the western border of the whole Atlantic belt, from the Gulf of St. Lawrence to Alabama, have, as is well known, a general high dip to the eastward, attended with many dislocations, folds, and inversions; as a result of which the newer sediments appear to pass beneath the older ones, and even beneath the still more ancient crystalline rocks of the belt, giving rise to some of the most perplexing problems in American geology.

The fauna of the Upper Taconic rocks, including the forms found at Troy, New York, at Georgia, Vermont, and at Phillipsburg, Point Levis, and Bic, in the province of Quebec, presents, as far as known, nothing lower than the Menevian horizon, and belongs to the Lower and Middle Cambrian of Sedgwick. The quartzites and magnesian limestones around the Adirondack region, and in the geographically similar area of the Upper Mississippi, which are generally included under the names of the Potsdam sandstone and the Calciferous sand rock, or Lower Magnesian limestone, appear, in the present state of our knowledge, to have been deposited during the Upper Taconic period.

The whole of these rocks are wanting along a great part of the northern outcrop of the Siluro-Cambrian in Canada, where the limestones of the Trenton group repose unconformably upon crystalline eozoic (pre-Cambrian) rocks, and moreover appear as outliers still farther north, resting upon these. The Chazy limestone, a formation comparatively limited in its distribution, appears by its fauna to connect the Cambrian rocks with the Siluro-Cambrian, represented by the Trenton

limestone and the succeeding Cincinnati series, which includes the Utica slates and the Loraine, or Pulaski shales. These, passing from Ontario southeastwards, along the west side of the Adirondacks, become thinner, and, according to Conrad and Vanuxem, disappear entirely in the Mohawk valley. The Pulaski shales are said by the latter to be underlaid in this region by the Frankfort shales and sandstones which, after the disappearance of the Pulaski shales, form the surface-rock eastward to the Hudson, and were regarded as the lower portion of the Hudson-River slate group, then supposed to overlie the Trenton limestones. According to the later determinations of Emmons these slates are Upper Taconic, and, the Trenton limestone being absent, the Loraine, the upper member of the Siluro-Cambrian, is found in outliers, resting unconformably upon these Upper Taconic (Cambrian) slates.

The Oneida conglomerate and sandstone (which forms the base of the true Silurian in New York and in Pennsylvania) rests upon the Loraine shales near Lake Ontario; but where these disappear, to the southeast, lies, in Oneida County, upon the Frankfort slates. If these latter are really Cambrian, the whole of the Siluro-Cambrian would be wanting in this region. In the eroded anticlinal valleys west of the Susquehanna River, where the whole of the Siluro-Cambrian is present, the passage from the Upper Cambrian (Cincinnati) shales into the Silurian sandstones is gradual, and there is no stratigraphical break, although, as shown by Rogers, such an interruption occurs between these same sandstones and the underlying (Frankfort) slates along the northwest border of the great Appalachian valley.

The Lower Taconic series of Emmons, embracing in ascending order (1) granular quartz rock, (2) the Stockbridge limestone with its interstratified and overlying micaceous schists,

and (3) argillites, including roofing-slates, constitutes a distinct geological horizon of rocks essentially crystalline, having an aggregate thickness of about five thousand feet. These are found resting alike on Laurentian, Huronian, and Montalban strata, and are overlaid, probably unconformably, by the Cambrian (Upper Taconic). In opposition to this view of the age of the Lower Taconic, which was that originally put forward by Emmons, it was maintained by H. D. Rogers that the limestones of the series are of the age of the Calciferous and Chazy; by Mather, and later by Dana, that they are Trenton; by Adams, and others, that they are either Lower Helderberg or Devonian; and finally, by Logan, that they are the Levis limestones of the Upper Taconic, — in all cases modified by so-called metamorphic agency.

Of these four irreconcilable views, each one in its turn has been plausibly defended upon the ground of apparent superposition to, or of association with, fossiliferous strata of various ages, in some one or more localities. All of these hypotheses are, however, in the author's opinion, equally untenable, and the true position of these limestones, as maintained by Emmons, is believed to be inferior to the Upper Taconic or to the Potsdam sandstone. They are apparently identical with the great limestone series which, in Hastings county, Ontario, underlies unconformably the Trenton group of limestones, and near St. John, New Brunswick, is beneath the Menevian slates. Whether these Lower Taconic limestones and slates, with their underlying quartzites, are the equivalents of the basal beds of the Cambrian in Scandinavia is not certain, and in view of their great geological importance in North America, it seems proper, while referring the Upper Taconic, as has already been done, to the Cambrian, to preserve for the lower group the original name of Taconic or, better, Taconian.

The rocks of the Taconian series, though in part detrital, are, as already said, essentially crystalline, and although distinct alike from the Montalban, Huronian, and Laurentian series, which succeed them in descending order, have certain lithological resemblances with each of these. Mather, whose views were adopted without question by a great number of American geologists, supposed all of these unlike groups of rocks to be nothing more than Cambrian and Siluro-Cambrian strata, constituting the Champlain division of the New York system. These, including the succession from the base of the Potsdam to the summit of the Loraine, were supposed to have been modified in a greater or less degree by intrusive rocks, and by unknown agencies, and to have assumed, in different localities, the four forms of the Upper Taconic, the true Taconian, the Montalban and Huronian schists, and the gneisses and crystalline limestones of the Laurentian.

To-day, the greater part of this extraordinary hypothesis is, by most geologists, rejected; and it is seen that the dissimilarities in these great crystalline series cannot be explained by supposing them to result from subsequent and unlike changes, in different areas, of one and the same uncrystalline paleozoic series. These lithological differences, as exhibited in the Highlands of the Hudson, in the crystalline rocks of the Green Mountains and White Mountains, and in those of the Taconic hills, correspond to four great series of pre-Cambrian rocks, and mark as many successive periods in eozoic time.

As we pass westward beyond the influences of the great Appalachian disturbances which have faulted, folded, and inverted alike these eozoic formations and the succeeding paleozoic strata, the problem of the relation between the two becomes much less complicated and more readily understood.

In the great area south and west of Lake Superior, where the Cambrian formations are everywhere undisturbed and unaltered, it is clearly and unmistakably seen, as Irving has so well shown, that the Laurentian, Huronian, and Montalban rocks (there, as in the east, greatly folded and contorted) are far older than they. The Taconian, with its characteristic limestones, does not appear in this northwestern region, but we find in the same geological interval the great volcanic series of copper-bearing strata which is displayed in the Keweenaw peninsula. These rocks, successively referred by different observers to the mesozoic period, to the age of the Potsdam, and to the so-called Quebec group, are now clearly shown by the geological survey of Wisconsin, to pass, in their southwestern prolongation through that state, unconformably beneath the horizontal fossiliferous Lower Cambrian sandstone, which is in part made up of their ruins. This great metalliferous series, which the author has distinguished by the name of Keweenian, he has found to contain in its conglomerates the gneisses of the Laurentian, the petrosilexes, greenstones, and chloritic schists of the Huronian, and the characteristic mica-schists of the Montalban.

The Taconian rocks, which are conspicuous in the great Appalachian valley from Vermont to Alabama, are characterized by many lithological peculiarities. The magnesian limestones of the series sometimes contain serpentine and mica, often finely disseminated, while the associated schists are sometimes in large part made up of a hydrous mica. Garnet, chlorite, and crystalline oligist and magnetite ores, are also found abundantly at this horizon, and the whole series of quartzites, limestones, and interstratified schists constitutes a group very distinct in its lithological characters from the older crystalline groups. These Taconian rocks include great

beds both of carbonate of iron and pyrites, and from the oxydation of the one and the other, *in situ*, as has been shown by the author, have been derived the great masses of brown hematite ores everywhere found along the outcrop of the series. The clays often accompanying these ores are the results of the decay of the enclosing crystalline schists, which, like the still older crystalline strata along the eastern border of the Appalachian valley, are in many places decomposed to considerable depths.

The direct evidences of life in these Taconian rocks are the marks of some organic form which have been described under the name of *Scolithus*, and appear to be common to the quartzites and the limestones; while the latter contain, moreover, fragments of an undescribed linguloid shell. In some few localities the existence, among areas of the Taconian limestones, of strata containing recognized paleozoic forms has been noticed. This older series was, however, overlaid both by Cambrian and Siluro-Cambrian strata, which were afterwards subjected to disturbances completely inverting the order of these latter, and involving at the same time in their folds and dislocations underlying strata alike of Taconian, Montalban, Huronian, and even of Laurentian age, to such an extent that all of these, in their turn, have, as we have seen, been regarded as altered paleozoic strata. Thus, in repeated instances, Siluro-Cambrian rocks are overlaid by others which are clearly Cambrian sediments, while these latter are found to pass beneath the crystalline rocks of the Atlantic belt called by Logan "altered Quebec group" (Cambrian). These, however, as was long since pointed out by the writer, are pre-Cambrian rocks of Huronian age. The investigations of the geological survey of Canada within the last two years have fully vindicated this view, as it was set forth in pages 276

and 408 of the present volume. In the limestones and slates referred above to the Taconian, which, in Madoc, Ontario, lie between the Huronian and the Trenton (which latter rests upon them unconformably), there have been found by Dawson, besides Scolithus-like markings, the remains of Eozoon not unlike that of the Laurentian.

The Alps, where similar geological accidents to those of the Atlantic belt in North America involve not only paleozoic but mesozoic and even cenozoic strata, have been the object of similar hypotheses to that of Mather, and the crystalline rocks of that region have been, in turn, assigned to every one of these periods (see pages 334–346). The late researches of Gastaldi and others have, however, shown the fallacy of these views, and established a complete harmony between the geology of the Alps and that of our Atlantic and Mississippi regions. At the base, according to Gastaldi, is a great series of gneisses, often granitoid and porphyroid, associated with quartzites, graphite, and crystalline limestones, the whole of which is referred by him to the Laurentian. A second series of great thickness, known as the greenstone or *pietri verdi* group, consists of varieties of diabase with serpentine and chloritic, steatitic, and epidotic strata, associated with quartzose and calcareous schists.

These rocks, which are widely spread in northern Italy, have been by most geologists looked upon either as eruptive, or as contact deposits resulting from the action of eruptive masses upon uncrystalline sediments, and from their supposed stratigraphical relations have been assigned to very different geological ages, from the eocene to the Silurian. Gastaldi, however, concludes that the *pietri verdi* are not eruptive, but indigenous, and constitute a well-defined series of great thickness, pre-paleozoic in age, resting unconformably upon the

Laurentian, and referred by him to the Huronian, of which it has all the characters. To this succeeds another great group consisting of quartzites with limestones and dolomites, sometimes schistose and micaceous, including, near the summit, gypsum and anhydrite. These also have, in turn, been assigned to various geological horizons from the tertiary downward, but, according to the same observer, are, if not prepaleozoic, at the very base of the paleozoic series. Similar views with regard to the crystalline rocks of the Alps have been arrived at by Favre, and by Giordano and Gerlach.

The Origin of Crystalline Rocks has been discussed at some length in this volume, where, on pages 285, 286, the two principal hypotheses proposed to account for the mineralogical composition of such rocks are concisely stated. The first of these supposes that the minerals of which many of these rocks are composed "have resulted from an alteration of previously existing minerals of plutonic rocks, often very unlike in composition to the present, by the taking away of certain elements and the addition of certain others." This change, which in the individual mineral is called epigenesis or pseudomorphism, is designated metamorphism or metasomatosis when applied to rock-masses. An attempt is made on page 295 to give, in general terms, the views of those who maintain this hypothesis of the origin of the crystalline schists; and the extent to which it has been carried by certain of its advocates is fully shown on pages 319, 320, 324, 325, and 326.

In opposition to this hypothesis, which supposes that the various crystalline silicated rocks have been derived from plutonic masses by epigenic changes, effected through aqueous agencies, is that maintained by the author, according to which the crystalline stratified rocks are not plutonic but neptunean in origin, and, except so far as they are mechanical sediments

coming from the chemical or mechanical disintegration of more ancient rock masses, "were originally deposited as, for the most part, chemically formed sediments or precipitates, in which the subsequent changes have been simply molecular, or at most confined to reactions, in certain cases, between the mingled elements of the sediments." This view is illustrated at length on pages 296–300, where it is applied to silicates such as serpentine, talc, chlorite, hornblende, pyroxene, garnet, and epidote, all of which are conceived to have been "formed by a crystallization and molecular rearrangement of silicates generated by chemical processes at the earth's surface." The formation of crystalline feldspar in veins, evidently of aqueous origin, is also cited as throwing light on the genesis of bedded feldspathic rocks, and, finally, the aqueo-igneous fusion of neptunean crystalline strata is supposed to give rise to plutonic masses (pages 285, 317).

Although the hypothesis of the plutonic and epigenic or metasomatic origin of crystalline rocks still counts many disciples, the doctrine of their neptunean origin has found favor with some of the most enlightened students, as has been shown on pages 304, 305, 316, and 317. Prominent among these is Delesse, who, as we have seen, early renounced the plutonic for the neptunean theory of crystalline rocks. He has, since the printing of the first edition of this volume, given further expression of his views on this question in a critical notice of the writings of the plutonists, Von Lasaulx and Knop. According to Von Lasaulx all crystalline rocks have been derived from the primitive crust of the globe, which he supposes to have been of a granitic character. The changes wrought therein have consisted, first, in the mechanical disintegration of portions, and their conversion into sedimentary rocks, and, second, in chemical alterations alike of these and

of the primitive igneous rock. In this way granite or gneiss has been converted, by the loss of alkali, successively into mica-schists and argillite, while other alterations are supposed to have given rise to chloritic and talcose minerals.*

According to Knop the plutonic rocks themselves have originated by a similar process from volcanic products. Granite is, in his view, a metasomatic eruptive rock, derived from a trachytic lava, while gneiss is formed from the detritus of trachyte or of granite. The final result of the metasomatosis of these materials (which is supposed to be effected through water, at great depths, under heat and pressure) is a mixture of quartz and mica. Doleritic lavas by similar transformations give rise to the various greenstones. Knop also admits another and very different origin for crystalline schists. The kaolin resulting from the superficial decomposition of granitic rocks may, by the fixation of alkali, be successively converted into mica and feldspar, so that a plastic clay, by such a process, might be changed first into argillite, then into mica-schist, and finally into a gneiss.† A similar hypothesis has been maintained by others, and the introduction of foreign elements in solution has been conceived to play an important part alike in the alteration of uncrystalline sediments and of plutonic rocks.

These latter reactions are doubtless possible in the laboratory, but the assumption that they, or the metasomatic changes imagined by Von Lasaulx and Knop, are concerned in the genesis of the crystalline rocks is a gratuitous hypothesis, meriting the epithet of "métamorphisme à l'outrance," given by Delesse. In opposition to the views of metasomatosis, this writer asserts that "the varied characters of the

* Poggendorf's Annalen, vol. 167, page 304.

† Neues Jahrbuch für Mineralogie, 1872, pages 388 and 490.

crystalline schists are not due to their having passed through a greater or less number of metamorphoses, but, on the contrary, depend essentially upon the primitive composition of the sediments from which they are formed, and also upon the development of their crystalline structure." He then proceeds, in accordance with the author's view, to consider how, owing to the different chemical composition of these sediments, there have been formed, in one case, feldspathic rocks, in another hornblende and pyroxene, in another serpentine, talc, and chlorite, and in still others andalusite, cyanite, staurolite, and micas.

Von Lasaulx, from the microscopic study of a porphyritic protogine and its contiguous talcose and micaceous schists, concludes that these have resulted from an alteration, in place, of portions of the porphyry; but Delesse, with reason, maintains an original difference in the rocks both in composition and in structure, and further remarks that the microscopic study of minerals and rocks, while rendering important services, "has greatly contributed to the rise of geological theories which appear to be inadmissible, particularly as regards metamorphism, showing how much reason De Saussure had to say that mountains should not be studied with microscopes."

With regard to the hypothesis of the epigenic or pseudomorphous production of mineral species, which underlies the plutonists' theory of metamorphosis or metasomatosis, Delesse uses the following language: "Metamorphoses the most improbable, and in any case the least proved, have been admitted by a whole school of mineralogists. It is thus, for example, that orthoclase is (by them) connected on the one hand with a volcanic mineral, leucite,—from which they would derive it,—and on the other with potash mica, supposed to be formed from the orthoclase. With the help of the chemical formulas

of these minerals they show that leucite can be successively transformed into analcime, orthoclase, and kaolin, and finally into a potash-mica. Although the change of some of these minerals may take place in certain points, — especially the change of orthoclase into kaolin, — no one has ever yet observed the gradual and complete series of all these transformations in any given locality, and they are entirely hypothetical."* The reader may compare the above citations from Delesse with the language of the author on pages 287 and 324 – 326 of this volume.

J. D. Dana, who in 1845, 1854, and 1858, gave expression to the extreme views of the plutonist school as to the origin of crystalline schists by pseudomorphism, which have been cited on pages 319 and 320, declared in 1874 that these extracts from his writings "did not express the opinions on metamorphism which he had held for the past twelve years"; but that the "Manual of Geology," published by him in 1863, "is to be taken as a correct expression of its author's views on this question." † The definitions of the Manual on this important matter, which have already been noticed on page 321 of this volume, although leaving much to be desired, permit the conclusion that its author has abandoned his former opinions on metamorphism.

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* Bull. de la Soc. Géol. de France, 3me série, Vol. III. pp. 154 – 160.

† Proc. Bost. Soc. Nat. Hist., Vol. XVII. p. 169 and Vol. XVIII. p. 200.